UNCERTAINTY PRINCIPLE AND INTERPRETATION OF THE COLLINEAR CLUSTER TRI-PARTITION PHENOMENON

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In the present talk features of the phenomenon we deal with at this section – so called collinear cluster tri-partition – are analyzed from various viewpoints:

1. Limitations on the angular distributions which are imposed by the general principles of quantum mechanics are considered.

2. These limitations together with the experimental data published earlier are used to estimate the total yield of CCT.

3. Some confirmations of the large yield of the lightest component produced by the tri-partition process arising from geochemical data are presented.

4. Some indirect schemes of validation of the effect are proposed.

CCT-PHENOMENON. OBSERVATION

Fundamentally new results in physics of nuclear fission were obtained in experiments using FOBOS and COMETA devices (Previous talks, Yu. V. Pyatkov, Phys. Rev. C 96, 064606 (2017) and references therein). The fragments with A1 ~128÷146 ("Sn-like") and A2~64÷80 ("Ni-like") respectively were observed in 252Cf spontaneous fission.

The most surprising results of the experiments are:

1. The missing lightest object has the unique mass A3 ~ 50.
2. In the FOBOS setup the coincident events are registered at the angle 180 ± 2º, thus the detected fragments A3~50 (“Ca-like") are also highly collinear in these observations.
3. A great branching ratio of the CCT-events $4 \cdot 10^{-3}$ relative to the total number of the registered fission events is observed.

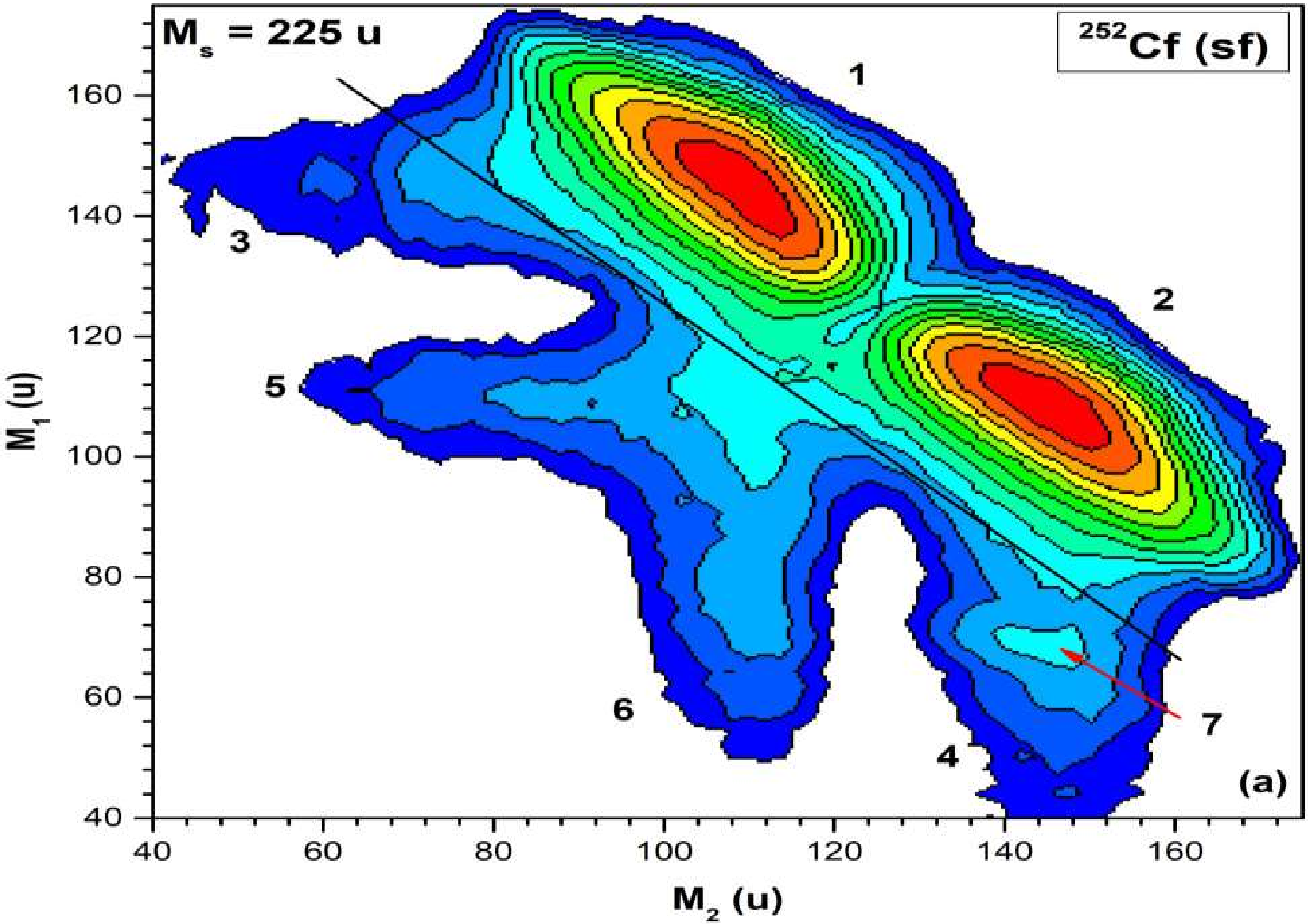


Fig1.Mass distribution of 252Cf fission fragments.

In the latest papers of the group another unexpected feature of the process has been revealed: the yield of the low-energy E ~ 20 MeV Ni-like fragment in the COMETA experiment turns out to be the most probable.

Similar collinear Sn- and Ni-like fragments were detected in 235U(n,f) process by the same group. The missing object has the mass A ~ 36÷38 (“Si-like“ fragment) .

A number of papers concerning the subject, both criticizing (P. Holmvall et al, Phys. Rev. C 95, 014602 (2017)) and supporting (Phys. Rev. C 94, 064615 (2016); Eur. Phys. J. A 52, 135 (2016); Phys. Rev. C 90, 024601 (2014)) were published last years.

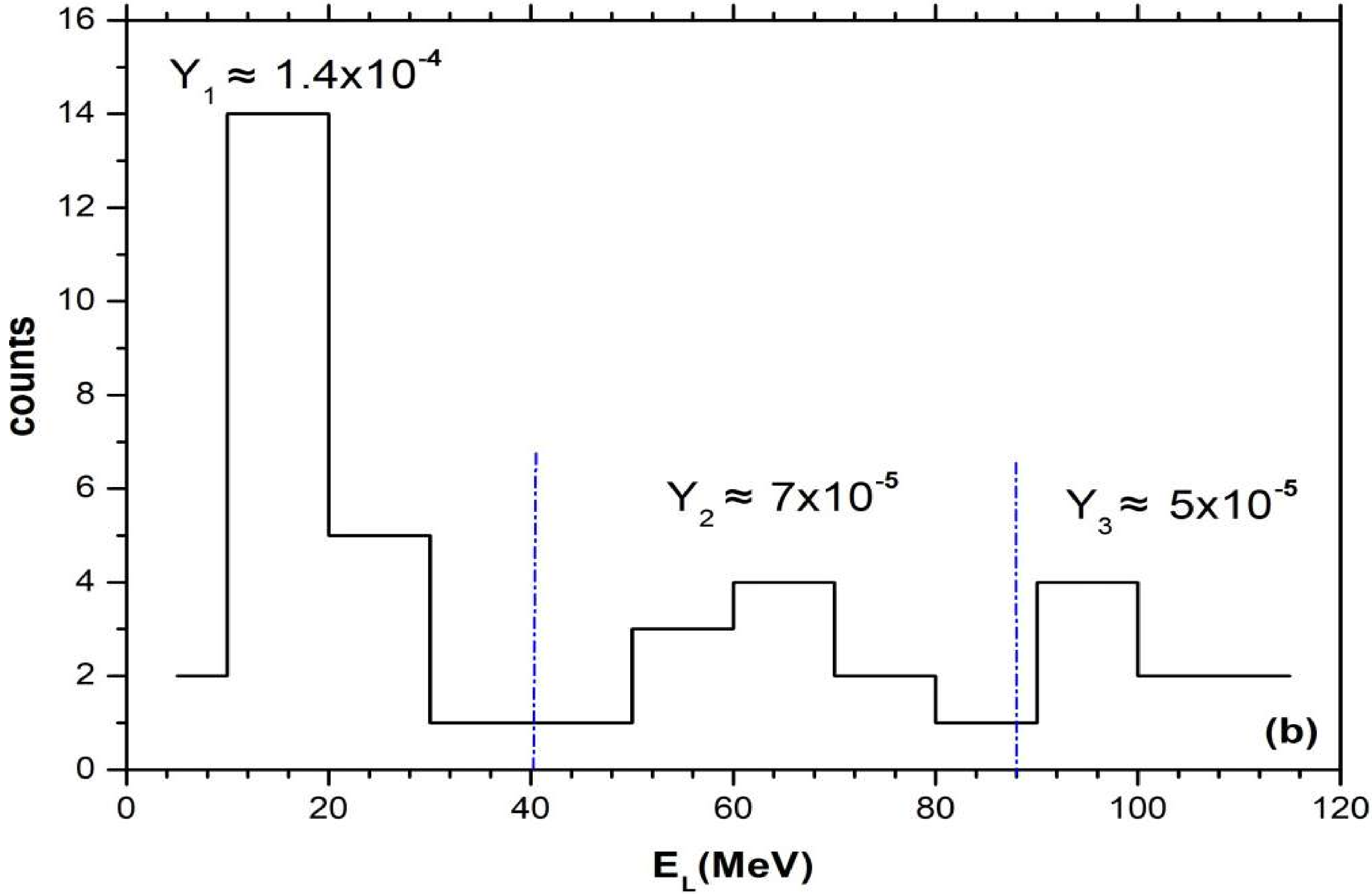


Fig. 2. Energy distribution of Ni-like fragments in 252Cf spontaneous fission.

UNCERTAINTY PRINCIPLE AS APPLIED TO CCT-PHENOMENON

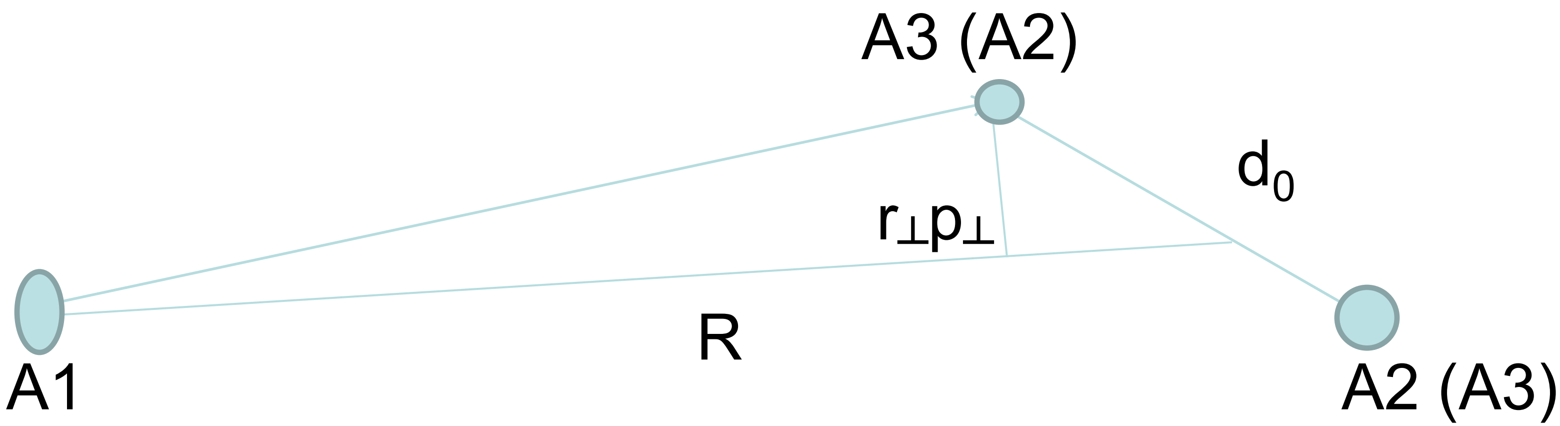
A preliminary estimate may be obtained using the angle - angular momentum uncertainty principle expression

$$(\Delta L_k)^2(\Delta \sin\varphi)^2 \geq \hbar \qquad / 4$$

where L_k is the projection of the angular momentum on *k*-axis. Taking into account that the angular momentum distribution of fission process is limited by the value L_{max} ~10ħ one can estimate the width of the angular distribution cone φ≥5º. Moreover it is necessary the cone to be formed by a very specific superposition of the Legendre polynomials. So the actual distribution may be essentially wider.

The just presented estimate, however, is valid for the simultaneous but not for the sequential process in the case that any mechanism giving rise to orientation of the axis of a primary split product deformation takes place. Indeed, the angular momentum of a product of the secondary split is unlimited for a sequential tri-partition.

To analyze the sequential tri-partition case a more accurate approach can be applied.



It is clear that the larger is the distance R, the smaller is the lateral linear momentum at the infinity. So its minimum is reached for the sequential process. For the lateral components of the distance and the linear momentum at the scission point $\Delta r_{\perp 0}$ and $\Delta p_{\perp 0}$ one can obtain the expression for the lateral component of the linear momentum of each fragment at the infinity $p_\perp$:

$$\Delta p_\perp = pr_{\perp,0} / d + p_{\perp,0};$$

where

$$d = d_0 m_3 /(m_2 + m_3)$$

and

$$p = \sqrt{2Z_1 Z_2 e^2 m_2 m_3 / d_0 (m_2 + m_3)}.$$

Using general formula of root mean square deviation

$$\Delta F = \sqrt{\sum_{i=1}^{n} \left\langle (\partial F / \partial x_i)^2 \right\rangle (\Delta x_i)^2}$$

and habituated expression of indeterminacy principle

$$(\Delta r_{\perp 0})^2 (\Delta p_{\perp 0})^2 \geq \hbar$$

one can obtain

$$\Delta p_{\perp} = \sqrt{(p / d)^2 (\Delta r_{\perp,0})^2 + (\Delta p_{\perp,0})^2}$$

As a result one can express the lower limit of the value $p_{\perp}$ in the following form:

$$\Delta p_{\perp} \geq \sqrt{(p/d)^2 (\Delta r_{\perp,0})^2 + \hbar \quad \ldots \quad _{\perp,0})^2}$$

After deducing the minimum of the radicand the formula of the minimal value of the width of the angular distribution cone in the laboratory frame takes the following form:

$$\Delta\varphi \geq (Z_2 Z_3 e^2 / 2\mu c^2)^{1/4} (\hbar \quad \ldots \quad ^{/2} d_0^{-3/4}$$

The value R≥100 fm is sufficiently large to neglect the influence of the first fragment. So there is no difference in angular distribution of sequential and “almost sequential” mechanisms.

NUMERICAL ESTIMATES

Let us fix three variants of distance d_0: contact distance, the same + 2 fm, and d_0 =16 fm and the values of Ni-like fragment energy corresponding to the energy maxima presented in Fig.2.

E_{lab} (MeV)	d_0 (fm)	9.4	11.4	16.0
20		11.7	9.2	7.9
100		5.2	4.1	3.5

TABLE I: The lower limit of the width of the angular distribution cone of the Ni-like fragment, grad.

In the case that the Ni-like fragment is slow (and thus turns out to be central) the distribution cone is much wider than the experimental angular "window". So no one nuclear process could provide the sharp collinearity.

The possibility of the angular distribution width to be much greater than 2 was rejected in the previous papers at the very beginning. The reason is probably that in that case the CCT yield would be enormously great due to the quadratic dependence of the yield on the angular width of the distribution cone. Indeed, the values of the relative CCT yield conforming to the typical minimal angular widths 4º, 8º, and 9º obtained in the current study are equal to $1.6 \cdot 10^{-2}$, $6.4 \cdot 10^{-2}$, and $8.0 \cdot 10^{-2}$.

At first glance the presented values go far beyond the area of acceptable quantities. Nevertheless, surprisingly, there is a supporting evidence for this possibility. It was obtained in the geochemical researches. Excess of 38 and 40Ar isotopes in uranium ore was analyzed in these studies. The results are presented in details in monograph (Yu. A. Shukolukov, Fisson of uranium in nature (Atomizdat, Moscow, 1970 (in Russian)). These excess isotopes may be in principle the residues of CCT process.

Abnormal abundance of 38Ar in various samples of the uranium ore is well-confirmed fact. A typical ratio of abundances A38/A36 in the samples extracted from various deposits is on the average 8 times greater than in the atmosphere.

A detail analysis of origins of that was performed because the nuclear reactions induced by neutrons and alpha-particles which are generated by uranium and its secondary products bring about formation and destruction of argon isotopes. Five of them:

35Cl(,n)38K, 35Cl(,p)38Ar, 35Cl(n,)36Cl, 37Cl(n,)38Cl, and 41K(n,)38Ar

exert primary impact on the Ar isotopes abundances.

Correlations between Ar and Cl isotopes as well as Ar and K isotopes were studied. Searches for the correlations of isotope abundances in various uranium deposits, as well as the correlations of location of these isotopes in the crystal structure of one and the same sample were performed.

No a correlation was revealed. So the reactions under discussion play a minor role in 38Ar isotope production. Effects related to the diffusion of Ar isotopes from the ore were also analyzed.

The principal conclusion made by Yu. A. Shukolukov is that most of the excess 38Ar is probably produced by a spontaneous decay process of uranium nuclei. According to author's estimates the yield of the radiogenic 38Ar is about one order of magnitude smaller than the total yield of the products of 238U spontaneous fission process.

This result looks exotic but is in a good agreement with the just presented estimates of the CCT yield.

It should be noted that the results of geochemical analysis have to be used with a certain caution. Indeed, the same approach being applied in the study of the production of 40Ar in the same 238U spontaneous decay process resulted in the unlikely high relative probability of this process and the result should undoubtedly be rejected. At the same time there is a significant difference of two results under discussion.

The matter is that the one related to 40Ar isotope excess was deduced by measuring of A40/A38 ratio only.

There is another feature which poses great difficulties to deduce a reliable value of 40Ar yield in some 238U spontaneous decay process. It is the great "background" appearing due to the dominating source of radiogenic 40Ar namely the beta-decay of 40K. So the failure of the approach in the description of 40Ar yield in some 238U disintegration does not mean that it is inadequate to describe another example, 38Ar yield in particular.

SUMMARY

In the current study the limits imposed by quantum mechanical principles on angular distribution of a tri-partition process are deduced.

The estimates give a proof that the nuclear ternary scission process can not be precisely collinear in principle. The concept of approximate collinearity of this process is meaningful only. It is demonstrated that only the sequential and "almost sequential" mechanisms may result in approximately collinear events.

It is shown that the extremely large yield of lighter fragments evaluated from the published data and estimations of actual angular distribution cone is in a good qualitative agreement with geochemical data.

The performed estimates may be used in design of corresponding experimental setups. These approaches are the following.

1. Search for the quasi-collinear events characterized by significant (>5º) deviation from collinearity.

2. Use of the method of photo-emulsion detecting of scission fragments. A marker of the CCT is the elliptic cone form of the trace of a pair of quasi-collinear fragments. Indeed, a single fragment makes the circular cone trace.

3. Study of isotopic composition of argon in a nuclear reactor wastes.

THANK YOU FOR YOUR ATTENTION!